Adoption of GM Food Crop Varieties in the European Union

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Abstract: Bio-safety issues and food-safety concerns have delayed the adoption of GM crop varieties in the food chain of the European Union (EU). Previous general equilibrium studies of welfare effects have focused on analyzing possible changes in consumer preferences. The point of departure for the current study is that consumer preferences are invariant. Instead, policy-relevant limitations for the adoption of GM crop varieties in the EU are considered to include (i) lack of (approval of) appropriate GM varieties for the EU area, (ii) lack of marketing of GM products due to first mover issues among commodity retailers, (iii) lack of trustworthy certification schemes addressing heterogeneous information needs among consumers, (iv) (excessive) national coexistence regulation and country-specific insurance problems, and (v) lack of a concerted effort by national and EU institutions including technical support and farmer-to-farmer interactions. Simulations with a global GE model point to the existence of important trade-related spillover effects on regions with little own production of GM food crops. Hence, the results suggest that EU have benefitted, strongly, from existing GM adoption on the consumption side (spillover effects from imports of GM products), and that they are likely to enjoy strong additional benefits from increased future GM adoption on the production side. However, the results also suggest that EU may have an equal interest in promoting GM adoption at home and abroad.

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1. Introduction

Bio-safety issues and food-safety concerns have delayed the adoption of Genetically Modified (GM) food crop varieties in the food chain of the European Union (EU). At the same time, GM food crop adoption has proceeded at a rapid pace in other parts of the world (mainly the Western hemisphere). The trade implications of rapid adoption among natural exporters and slow adoption among natural importers have created tensions between trading partners within the World Trade Organization (WTO) system (Sheldon 2002). Partial EU adoption, on the consumer side, may have allowed EU and their trading partners to reap part of the potential welfare gains (from trade-related pecuniary spillover effects). In the context of partial EU adoption on the consumer side, a key question is to what extent increased EU adoption on the producer side will lead to larger benefits. In order to address this question, the current study attempts to quantify (1) *achieved welfare gains*, which have been achieved by existing GM food crop adoption in EU and other parts of the world, and (2) *potential welfare gains*, which can be achieved by increased GM food crop adoption in EU.

The measurement of welfare gains from GM agricultural crop adoption has received broad attention since GM crops were first commercialized in the mid-1990s. Two main lines of academic research have emerged including partial equilibrium (PE) studies (Falck-Zepeda, Traxler & Nelson 2000, Demont & Tollens 2004, Fulton & Giannakas 2004, Lapan & Moschini 2004, Qaim & Traxler 2005, Sobolevsky, Moschini & Lapan 2005, Berwald, Carter & Gruère 2006, Giannakas & Yiannaka 2008, Desquilbet & Bullock 2009), and general equilibrium (GE) studies (Nielsen & Anderson 2001, Nielsen, Thierfelder & Robinson 2003, Anderson & Nielsen 2004, van Meijl & van Tongeren 2004). The theoretical PE literature has focused on analyzing (domestic and international) welfare distribution, while the empirical PE literature has focused on measuring the level of welfare benefits from single GM crop adoption. Other non-academic PE studies have employed a bottom-up aggregation approach to measure achieved welfare benefits from the worldwide adoption of GM crops (Brookes & Barfoot 2006, 2008).

The PE literature has focused, narrowly, on the welfare implications for the agricultural sector. In contrast, the GE methodology allows for capturing key socioeconomic linkages and pecuniary externalities, which PE studies (to varying degrees) are ignoring, including trade-related welfare gains, downstream welfare gains from the wider GM food chain complex (e.g. animal feed), and welfare gains from other non-agricultural sectors (e.g. coexistence-related service providers). Only one previous GE study has attempted to segregate GM and non-GM food chains (Nielsen, Thierfelder & Robinson 2003). The main weakness of their study is that GM adoption rates are modeled through "changes in consumer preferences". This is at odds with the standard neoclassical approach where consumer preferences are assumed to be invariant. Furthermore, it invalidates the calculation of standard welfare measures. The current study follows the strategy of Nielsen et al. with the major exceptions that a more recent and comprehensive database is employed, and that the adoption of GM food products is modeled through changes in the calibration of the GE model. This approach ensures that household preferences remain unchanged between counterfactual and experiment, and thereby ensures that standard welfare calculations remain valid.

The underlying idea of this study is that future adoption of GM food products in EU will not be conditional on changes in consumer preferences. Consumer preferences are considered to be invariant. Instead, policy-relevant limitations for the adoption of GM food products in EU are considered to include (i) lack of (approval of) appropriate GM food crop varieties for the EU area, (ii) lack of marketing of GM products due to first mover issues among commodity retailers, (iii) lack of trustworthy certification schemes addressing heterogeneous information needs among consumers, (iv) (excessive) national coexistence regulation and country-specific insurance problems, and (v) lack of a concerted effort by national and EU institutions including technical support and farmer-to-farmer interactions. While solutions to the above issues are considered to be crucial for the determination of GM food crop adoption rates in EU, these issues are not explicitly modeled in the current paper. Instead, the resolution of these issues is subsumed in a sensitivity analysis.

In line with the existing GE literature, the current study employs the multi-region multi-sector Global Trade Analysis Project (GTAP) model framework (Hertel & Tsigas 1997). Our model specification contains five regions, including the three main GM food crop producers – Argentina, Brazil, and US – as well as EU-27 and Rest of the World (ROW). Furthermore, our model distinguishes between the three main GM food crops, including maize, rapeseed and soybean, and separates GM and non-GM food chains. Our welfare analyses attempts to capture both efficiency gains and coexistence-related costs associated with GM food crop adoption. The results indicate that EU-27 has been able to reap significant welfare benefits from GM food crop adoption on the consumer side, without having to employ biotechnological cropping systems on the producer side. Furthermore, the results indicate that the main GM food crop producers are likely to experience welfare losses from increased EU adoption on the producer side. This implies that EU-27 and the main GM food crop producers may have a shared interest in maintaining the current de facto hierarchical EU decision structure where the European Commission (EC) allows for GM adoption on the consumer side (due to their de facto control over the approval of GM food crop varieties), while individual EU member countries imposes de facto bans on GM adoption on the producer side (due to their control over national coexistence regulation). The rest of the paper is organized as follows: The existing literature is reviewed and discussed in section 2; The data base and model framework is discussed in section 3; Simulation results are presented and discussed in section 4; And conclusions are offered in section 5.

2. Background

The advent of recombinant DNA technology in the early 1970s was accompanied by public safety concerns, and, in spite of strong scientific consensus on the safety of biotechnology, these concerns have spilled over into the current debate about adoption of GM crops (Moschini 2008). In spite of widespread public concern, expressed most clearly by the regulatory activism in many EU member states, the GM share of global agricultural crop production has grown, strongly, over the past decade. The first strains of genetically modified Herbicide Tolerant (HT) crops and insect resistant crops (based on insertion of Bacillus thuringiensis (Bt) genes) appeared in the mid-1990s. Since 2000, the global area of GM crops has increased by an average annual growth rate of 14.5 percent (James 2007). By 2007, GM crops had increased their share of the global agricultural crop area to 16.5 percent, and the main part of the global GM crop area was planted with soybean (51 percent), maize (31 percent), cotton (13 percent), and canola (5 percent). Furthermore, the three main GM food crop producers, including Argentina, Brazil, and US, accounted for 86 Mio. Hectares (HA) out of a global GM food crop area of 99 Mio., and GM adoption rates in food crop production were, in each case, fairly high (Argentina: 55%, Brazil: 22%, US: 37%) (James 2007, FAO 2009).

The measurement of welfare gains from GM crop adoption has received broad attention. Studies may be classified according to three distinctions, including (i) partial equilibrium (PE) vs. general equilibrium (GE) studies, (ii) theoretical vs. empirical studies, and (iii) farm-level micro-data studies vs. simulation studies (among empirical studies). The PE model literature includes both theoretical and empirical studies, while the GE model literature is, purely, empirical. The theoretical PE studies are, in every case, based on the economic surplus methodology and focused on analyzing (domestic and international) welfare distribution (Fulton & Giannakas 2004, Lapan & Moschini 2004, Giannakas & Yiannaka 2008, Desquilbet & Bullock 2009).[1] In contrast, empirical PE studies, including (non-academic) bottom-up aggregation studies based on farm-level micro-data (Brookes & Barfoot 2006, 2008) and more complex (academic) simulation studies based on the economic

[1] The foundation for the theoretical partial equilibrium (PE) literature is the standard economic surplus approach (Alston, Norton & Pardey 1995). However, the PE literature on GM crop adoption extends the standard approach by e.g. accounting for the market power of GM seed monopolists (Moschini & Lapan 1997), the observed adverse response of consumer demand (Giannakas & Fulton 2002) and the heterogeneity of consumer preferences (Noussair, Robin & Ruffieux 2004, Lusk et al. 2006).

surplus methodology (Falck-Zepeda, Traxler & Nelson 2000, Demont & Tollens 2004, Qaim & Traxler 2005, Sobolevsky, Moschini & Lapan 2005, Berwald, Carter & Gruère 2006) has attempted to analyze the level of (global) welfare effects. Finally, the empirical GE studies are, in every case simulation studies, based on the so-called Global Trade Analysis Project (GTAP) model, and focused on analyzing global welfare effects (Nielsen & Anderson 2001, Nielsen, Thierfelder & Robinson 2003, Anderson & Nielsen 2004, van Meijl & van Tongeren 2004).

The empirical literature has, generally, focused on analyzing the adoption of first generation GM crops (improved production efficiency).[2] Furthermore, the (academic) PE studies, based on the economic surplus approach, have focused on measuring welfare effects from *pure efficiency gains* (Falck-Zepeda, Traxler & Nelson 2000, Demont & Tollens 2004, Qaim & Traxler 2005), and from *efficiency gains and coexistence-related costs* (Sobolevsky, Moschini & Lapan 2005, Berwald, Carter & Gruère 2006) associated with *adoption of single GM crops*. [3] In contrast, (non-academic) PE studies, based on simple aggregation of farm-level micro-data, have attempted to measure welfare effects from *pure efficiency gains* associated with *worldwide adoption of major commercialized GM crops* (Brookes & Barfoot 2006, 2008). The most recent of the latter studies estimated the worldwide farm income benefit, from existing GM food crop adoption, to be 4.0 bio. US$ in 2006.

The academic PE literature, based on the economic surplus approach, have been useful for analyzing the importance of key parameters (including consumer aversion, seed company monopoly power, efficiency gains, and coexistence-related costs) for the distribution of welfare benefits between sector-specific agents (including farmers, consumers, and seed companies). However, the literature, generally, suffers from important measurement problems when it comes to measuring the

[2] Second and third generation GM food crops are being developed, currently, with the purpose of improving the nutritional profile of food crops, including improved content of proteins, minerals, and vitamins, and with the purpose of producing proteins with pharmaceutical and industrial applications (Moschini 2006, 2008).

[3] "First order" efficiency gains and coexistence-related costs are not the only consequences of GM crop adoption. E.g. HT technology has contributed to increased use of conservation tillage and integrated management approaches, which allows for reduced labor, machinery, fuel, and fertilizer input use, as well as for increased soil conservation and drought tolerance (compared to conventional competitive practices). Conservation tillage has been widely adopted in e.g. Argentina and Brazil, and is currently applied to 43 percent (40 Mio. HA) of arable land in the region (WDR 2008). The adoption of HT soybean and HT canola, and the application of "burn-down" pre-seed herbicide treatment, has also contributed to increasing use of conservation tilling in US and Canada (Brookes & Barfoot 2008). Furthermore, the adoption of HT soybean has allowed for new intra-annual crop rotation schemes in e.g. Argentina (Brookes & Barfoot 2008), while the adoption of Bt maize has allowed for increased production quality of maize crops through reduced levels of mycotoxins in e.g. EU (Brookes 2008). Finally, GM crop adoption has, generally, reduced environmental stress due to reduced pesticide use and a switch to herbicides with a more benign environmental profile (Brookes & Barfoot 2008).

economy-wide level of welfare benefits: (i) welfare gains from increased production efficiency within the wider GM food chain complex are, typically, not fully accounted for, (ii) welfare gains from efficient reallocation of production factors are not, properly, accounted for, (iii) welfare effects of providing Segregation, Traceability, and Identity Preservation (STIP) services and insurance services (captured by agents outside the food value chain) is not accounted for, and (iv) income feedback effects among agents (e.g. farmers, consumers, seed monopolists, and STIP and insurance service providers) are ignored. Furthermore, non-academic PE studies suffer from additional measurement problems since they, completely, ignore trade-related welfare gains as well as welfare gains from the wider GM food chain complex (Brookes & Barfoot 2006, 2008). Hence, the applied (academic and non-academic) PE methodologies have, generally, been inappropriate for measuring economy-wide welfare effects of worldwide GM food crop adoption.

In contrast, the GE methodology, based on the multi-region multi-sector GTAP model, is uniquely suited to measure economy-wide welfare benefits of GM crop adoption, since it is able to capture key socioeconomic linkages and pecuniary spillover effects, including downstream welfare gains from the wider food chain complex, income feedback effects from farm income, enterprise income, and income of STIP and insurance service providers, pecuniary spillover effects associated with changes in relative world market prices, international production patterns and trade flows, and efficiency gains from reallocation of primary factor resources. Most empirical GE studies focuses on aggregate agricultural production sectors (Nielsen & Anderson 2001, Anderson & Nielsen 2004, van Meijl & van Tongeren 2004). One study has attempted to segregate GM and non-GM food markets including key agricultural food crops and wider food chain complexes (Nielsen, Thierfelder & Robinson 2003). However, they rely on an outdated database (base year: 1995) and impose standardized efficiency gains, including a uniform HICKS-neutral 10 percent productivity gain and a uniform 30 percent cost reduction for chemicals use, without paying attention to crop- and region-specific variation in efficiency gains. Moreover, in order to model the adoption rates of GM food crops, they rely on so-called “changes in consumer preferences”. This represents a major weakness of the study, since it is at odds with the standard neoclassical assumption of invariant consumer preferences, and since it, as such, invalidates the calculation of standard welfare measures.

The current study follows the strategy of Nielsen et al. with the major exceptions that (i) a more recent database is employed (base year: 2004), which takes account of crop- and region-specific variation in efficiency gains from GM food crop adoption (see tables 2-4), and (ii) the adoption of

GM food crops (and GM products in the wider food chain complex) is modeled through changes in the calibration of the CGE model, i.e. through changes in the counterfactual, instead of through preference shocks to the model. This approach ensures that household preferences remain unchanged between counterfactual and experiment, and thereby ensures that standard "equivalent variation" welfare calculations remain valid. First, variation in GM food chain adoption rates are used to establish four distinct databases and calibrate four distinct CGE models. Actual adoption rates are, in every case, imposed for non-EU regions, including Argentina, Brazil, US and ROW, while EU adoption rates vary between (1) actual adoption rates (base model), (2) 25 percent adoption rates, (3) 50 percent adoption rates, and (4) 75 percent adoption rates.[4] Second, the four distinct models are used to analyze the welfare impact of GM food crop adoption, conditional on the underlying GM food chain adoption rates. Efficiency gains are, in every case, analyzed by removing GM productivity improvements and GM input cost changes, while coexistence-related costs are analyzed by imposing price markups on non-GM food crops.

This study makes a specific point of distinguishing between adoption rates on the consumption side (which allows for capturing welfare gains from trade-related spillover effects) and the production side (which allows for reaping efficiency-related welfare gains). This distinction is unimportant at the global level, but proves important at the regional (EU) level. The literature has, generally, used the term "adoption rate" as a reference to adoption rates for both consumers and producers. However, the determination of adoption rates on the consumption side (based on e.g. the level of consumer heterogeneity) is fundamentally different from the determination of adoption rates on the production side (based on e.g. the level of producer heterogeneity and seed company monopolist power). The term "consumption side" covers both intermediate consumption (e.g. intermediate demand for GM food crops in the production of animal feed) and final consumption (e.g. household demand for GM vegetable oil). With this definition, EU-27 has a fairly large GM food chain adoption rate on the consumption side (as opposed to the production side), since large amounts of imported GM food crops and GM animal feed are used as intermediate inputs in e.g. meat and dairy production.

[4] Empirical PE studies, based on the economic surplus methodology, have attempted to model potential GM adoption rates from fully specified demand systems based on heterogeneous consumer preferences (Sobolovsky, Moschini & Lapan 2005). Nevertheless, it is unclear what is gained from this approach (apart from being a methodological innovation), since the parameter values of the demand system are guestimates, and since the results are sensitive to the parameterization. Hence, explicit specification (and sensitivity analysis) of adoption rates seems like a more direct (and less ad hoc) approach.

This study also attempts to measure the welfare impact of existing coexistence-related measures. At the worldwide level, coexistence measures are, mainly, applied to (segments of) non-GM products, which are, either, produced within or exported to EU. In spite of the lack of scientific foundation, the rejection of GM products, by certain consumer segments, has introduced a negative externality for existing cropping systems, which, by itself, has necessitated the introduction of (regulatory and non-regulatory) coexistence measures. Public responses include adoption of (non-proportional) coexistence regulation and "GMO-free zones" (Levidow & Boschert 2008, Devos et al. 2009). This is likely to have lowered GM adoption rates and increased coexistence-related price markups in EU. Furthermore, coexistence measures are likely to affect price margins for both GM and non-GM products and to be endogenously determined by the relative size of supply channels (Besquiet & Bullock 2009). Nevertheless, since little is known about the variation in markups between GM and non-GM products, this study will follow the existing literature and focus on measuring the welfare effects of fixed coexistence-related price markups on non-GM products, which are produced within or exported to EU.

Finally, this study makes a specific point of accounting for economy-wide welfare effects, including income gains for coexistence-related STIP and insurance service providers. Accounting for the welfare gains of service providers ensures that our welfare calculations will, properly, reflect the overall *economy-wide* welfare losses associated with coexistence-related price margins, rather than the *sector-specific* food-chain welfare losses which is accounted for in PE studies. In relation to trade in GM food crops, it is assumed that coexistence-related services are provided by the country of origin. E.g. it is assumed that coexistence-related services, associated with EU imports from Brazil, are supplied by Brazilian laboratories and other service providers. The coexistence-related service sector income gain will, therefore, be captured by Brazilian households, while margin-induced increases in food crop prices will be carried by EU households.[5]

[5] Coexistence-related service costs are likely to be carried, partly, by the exporting country (costs of maintaining separate supply chains, laboratory testing, labeling, etc.), and, partly, by the importing country (costs of laboratory testing, etc.) This study makes the extreme assumption that coexistence-related services are only provided by the country of origin. The following analysis is, therefore, likely to overestimate the welfare gains resp. welfare losses of the exporting resp. importing region. Nevertheless, the extreme assumption serves to make the point that (EU imposed) coexistence-related price margins may lead to welfare gains for other exporting regions. In the actual model implementation, coexistence-related costs are modeled as simple markup price wedges on producer prices (EU domestic production) and region-specific export prices (exports to EU), where the proceeds are transferred, directly, to the regional households.

[Table 1 around here]

3. Data base and model framework

This study employs a Computable General Equilibrium (CGE) model methodology. Previous CGE studies have employed the Global Trade Analysis Project (GTAP) model to analyze the welfare effects from future adoption of GM food crops (Nielsen & Anderson 2001, Nielsen, Thierfelder & Robinson 2003, Anderson & Nielsen 2004, van Meijl & van Tongeren 2004). The current study will also employ the GTAP model framework, to analyze the welfare gains from existing and potential future adoption of GM food crops. However, in contrast to previous studies, the current study will employ the more recent version 7 of the underlying GTAP database (base year: 2004) (Narayanan & Walmsley 2008).

The GTAP model is a static multi-region multi-sector CGE model (Hertel & Tsigas 1997), which is implemented using the GEMPACK software (Pearson 1997, Horridge, Jerie & Pearson 2008). The model framework is characterized by a nested region-specific production function structure, with a Leontieff specification at the top nest and Constant Elasticity of Substitution (CES) specifications at the lower nest, and a nested region-specific household utility function structure, with an Extended Linear Expenditure System (ELES) specification covering private consumption, government consumption and savings at the top nest, and Cobb-Douglass specifications for government consumption and savings, and a Constant Difference of Elasticities (CDE) specification for private consumption, at the lower nest. On the trade side, region-specific imperfect substitution between domestic production and imports are modeled through the use of a CES specification (the Armington assumption), while region-specific imperfect transformation of domestic production into export goods is modeled through the use of a Constant Elasticity of Transformation (CET) specification. International reallocation of savings depends on relative regional returns to capital, while international trade is facilitated by a global transportation activity, which demands regional transportation services according to a Cobb-Douglass specification, and supplies composite international transportation services which defines international trade margins.

In this study, the GTAP model framework is used to calibrate several distinct models, based on modified versions of the underlying GTAP database. The GTAP database had to be modified, to accommodate the focus of the current analyses. This study focuses on (i) existing adoption of GM food crops in EU and other parts of the world, and (ii) potential future increased adoption of GM food crops in EU. The main producers of GM food crops are, currently, Argentina, Brazil, and US. The GTAP database was therefore aggregated to five regions, including Argentina, Brazil, EU-27, US, and the Rest of the World (ROW). Moreover, the major GM food crops in world markets are, currently, soybean, maize, and canola. Separate accounts were, therefore, established for these three types of food crops. Finally, the methodology of the current study relies on the segregation of GM and non-GM food markets. Separate GM and non-GM accounts were, therefore, established for selected primary food crops, including soybean, maize, and canola, and for selected processed foods, including vegetable oil and other food processing (including animal feed). The disaggregation of the GTAP database relied on relative GM and non-GM food crop areas, and it was obtained by applying the Splitcom program (Horridge 2008). The assumptions underlying the disaggregation of food crop accounts and the segregation of GM and non-GM food chain accounts, is documented in Jensen, Jensen, and Gylling (2009). The structure of the GTAP database, including regional and sector level aggregation, is presented in table 1. [6]

[Tables 2-4 around here]

The main difference between GM and non-GM food crop production technologies lies in the structure of input costs. The input cost structures of the three main GM food crops were, therefore, modified to account for differences between GM and non-GM varieties. The crop- and region-specific assumptions about relative input cost structures are presented in tables 2-4. Evidence on differences in input cost structures between GM and non-GM food crop varieties are scattered. Hence, general assumptions had to be made. The first step was to gather information about relative input cost structures between competitive non-GM agricultural production practices and available GM agricultural production practices. Existing evidence suggests that the introduction of GM varieties of soybean leads to increased seed costs (+20 percent), while input costs decline for herbicides and other chemicals (-30 percent), own machinery (-15 percent), and labor (-10 percent) (Qaim & Traxler 2005). Other evidence suggests that the introduction of GM varieties of canola leads to increased seed costs (+20 percent), while other input costs remain virtually unchanged (CCC 2001). Finally, existing evidence on input costs structures for maize is fairly scattered (Brookes 2008). As a baseline, it was assumed that the introduction of GM varieties of maize leads

[6] The "Meat & Dairy" production activity uses GM feed as a production input. Nevertheless, it was not segmented into separate GM and non-GM production activities, since current (EU) labeling requirements are defined in terms of thresholds for laboratory test results, and since GM feed does not give rise to GM traces in meat and dairy products.

to increased seed costs (+20 percent) and reduced chemicals costs (-10 percent), while other input costs remain unchanged.

The evidence on relative input cost structures, presented above, relates to a comparison of competitive non-GM cropping systems and available GM cropping systems. These input cost structures were, therefore, imposed on the database for EU-27 and US. However, these relative input cost structures are not likely to be representative for Argentina, Brazil and ROW. In Argentina, license agreements, which raise the cost of GM seed inputs, are not enforced. Similarly, enforcement of license agreements in Brazil is likely to be undermined by the widespread growing of GM soybeans smuggled in from Argentina (Kent 2004, Sobolevsky, Moschini & Lapan 2005). In addition, Argentina and Brazil are developing countries.[7] Accordingly, the introduction of GM technology has allowed these countries to leap, directly, from traditional cropping systems to modern GM production practices. Traditional practices in these countries are characterized by relatively low inputs of chemicals. It was, therefore, assumed that seed and chemicals input cost structures are similar for GM and non-GM food crops in Argentina and Brazil – with one exception. Since license agreements are (partially) enforced in Brazil, it was assumed that seed costs are five percent higher for GM varieties compared to non-GM varieties, for all types of food crops in Brazil. In the case of ROW, license agreements are, generally, assumed to be enforced (implying relatively high GM seed costs). In contrast, widespread use of traditional agricultural production practices implies that chemicals input cost shares are likely to be similar for GM and non-GM food crops in ROW. The above considerations gave rise to the relative cost structures, presented in tables 2-4, and they were, subsequently, employed to disaggregate the food crop accounts of the GTAP database.

The final GTAP database includes five regions and covers 20 sectors (table 1), and reflects existing production patterns in 2004. This "basic" database were used to calibrate the base model, Model00, which allows for measuring the welfare gains from existing worldwide adoption of GM food crops. The base model does not, however, allow for welfare analyses of potential future increases in adoption rates. In order to allow for a sensitivity analysis of the welfare impact following from a potential future increase in GM food crop adoption rates in EU-27, there was a need to construct additional databases. Three additional databases were constructed to reflect (uniform) EU adoption rates of 25 percent, 50 percent, and 75 percent (on the production and consumption side). The

[7] For a general discussion of issues concerning biotechnology adoption in developing countries, see Falck-Zepeda (2006) and WDR (2008).

databases were obtained by applying the Splitcom program to the "basic" database. The economic structure of the three modified databases remained very similar to the actual economic structure in 2004. Input cost structures and trade shares were, virtually, unchanged. Rebalancing was achieved, mainly, through changes in individual EU import trade shares for GM and non-GM products (while preserving overall EU import trade shares). Export trade shares were left, virtually, unchanged (by proportional changes in exports and other final demand components). The modified databases were used to calibrate three models – Model25, Model50, and Model75 – which are used, in the next section, to measure the welfare impact of potential future increases in GM food crop adoption rates in EU-27.

[Tables 5-6 around here]

4. Simulation Results

Four distinct simulation models (table 5) are used, in this section, to analyze four types of experiments (table 6). The four models (Model00, Model25, Model50, and Model75) reflect different degrees of GM food crop adoption in EU-27. Model00, which reflects the actual pattern of GM adoption in global food crop production in 2004, will be used for experiments 1-3, while the remaining modified models will be used for experiment 4. Experiments 1-2 focuses on measuring achieved welfare effects from existing efficiency gains, while experiment 3 attempts to measure achieved welfare losses from existing coexistence-related measures. Experiment 4 undertakes a sensitivity analysis of potential welfare effects from efficiency gains associated with increased future EU adoption rates, where adoption rates are varied, uniformly, on the production and consumption sides, between 25 percent, 50 percent, and 75 percent.

The empirical GE literature, has, traditionally, not taken account of coexistence-related measures, while empirical PE studies have employed price markup sensitivity analyses with variation between 0-11 percent (Sobolovsky, Moshini & Lapan 2005) and fixed markups of around 5 percent (Berwald, Carter & Grùere 2006). In line with the existing literature, this study will assume that coexistence-related measures leads to a 5 percent price markup for (segments of) non-GM food products, which are, either, produced within or exported to EU. In relation to food crop production within EU, it is assumed that coexistence measures are, only, applied to organic production. Organic production accounts for 3 percent of the utilized agricultural area in EU (Moschini, Bulut & Cembalo 2005). Since organic crops are high-value crops, organic production is likely to account for a higher share of the overall production value. It was, therefore, assumed that the average coexistence-related price markup on (organic and conventional) non-GM food crops is 0.25 percent. Since the share of EU food crop imports which are affected by coexistence-related measures, is considered to be fairly small as well, the 0.25 percent price markup is applied, uniformly, to non-GM products which are produced within or exported to EU.[8]

[8] Coexistence-related costs are also likely to apply to processed food products. E.g. the need to produce both GM and non-GM food products at the same factory may require construction and maintenance of separate storage facilities, while specialization of factories may lead to logistics-related increases in input costs. However, little is known about coexistence-related costs for processed food products. Hence, the issue is not included in the current study.

[Table 7 around here]

Experiment 1 is used to measure the welfare impact of efficiency gains from existing worldwide GM food crop adoption in 2004 (table 7). The analysis is carried out by eliminating worldwide efficiency gains (productivity gains and changes in input costs) for the three GM food crops, including GM canola, GM maize, and GM soybean, for all regions, including Argentina, Brazil, EU-27, US, and ROW. The results indicate that the global welfare gain amounted to 5.8 bio. US$ in 2004. This GE estimate compares to a PE estimate of 4.0 bio. US$ in 2006 (Brookes & Barfoot 2008), and it suggests that general equilibrium effects, associated with the adoption of GM food crops, may be relatively strong.

[Table 8 around here]

Experiment 2 is undertaken to measure achieved welfare gains from existing adoption of GM food crops in EU-27 in 2004 (table 8). The analysis is carried out by eliminating EU-specific efficiency gains (productivity gains and changes in input costs) for GM canola, GM maize, and GM soybean, and the results indicate that EU welfare gains amounts to approximately 26 mio. US$, while the worldwide welfare gains amounts to 24 mio. US$. Hence, the existing adoption of GM food crops in EU agricultural production has led to negative spillover effects for Argentina, Brazil and the US (-9 mio. US$) and positive spillover effects for ROW (+7 mio. US$).

[Table 9 around here]

A comparison of the results from experiments 1-2 allows for computing trade-related spillover effects on EU welfare, i.e. to compute the welfare impact of EU adoption on the consumption side (e.g. GM animal feed), conditional on foreign adoption on the production side (table 9). The results suggest that EU-27 has achieved strong welfare gains from existing GM food crop adoption in the remaining parts of the world. Hence, EU welfare gains from GM adoption on the consumption side (657 mio. US$) are considerably higher than EU welfare gains from GM adoption on the production side (26 mio. US$). Furthermore, the results indicate that, due to strong trade-related spillover effects, EU-27 has managed to appropriate more than 10 percent of worldwide welfare gains from existing worldwide GM food crop adoption, without, barely, adopting GM food crops in agricultural production, themselves. The existence of strong trade-related general equilibrium effects underlines the importance of employing a global GE model framework when evaluating the impact of existing worldwide adoption of GM food crops. Furthermore, the existence of these spillover effects confirms that the magnitude of the global welfare effects, measured, in the current study, using a GE methodology, is consistent with the magnitude of global welfare effects, measured, in previous studies, using a PE methodology (Brookes & Barfoot 2008).

The results in table 9 also indicate that 87 percent of EU welfare spillover effects are due to the existing worldwide adoption of GM soybean (573 mio. US$). This result points to the importance, for EU-27, of having access to low-cost soybeans and derivative products. Trade-related spillover effects from existing worldwide adoption of GM maize (78 mio. US$) and GM canola (6 mio. US$) are much smaller.

[Table 10 around here]

Experiment 3 is used to measure achieved welfare losses from coexistence-related measures (table 10). The results indicate that an average coexistence-related 0.25 percent price markup on non-GM food crops, which are produced within or exported to EU, results in a relatively small global annual welfare loss (2 mio. US$). Regional welfare losses from increased consumer prices are slightly bigger and carried, entirely, by EU-27 (10 mio. US$). Interestingly, foreign exporters may experience welfare-improvements from (EU-induced) coexistence-related price distortions, to the extent that these regions supply the coexistence-related services, themselves. Accordingly, Brazil, (and to a smaller extent) Argentina and US experience welfare gains from providing coexistence-related services (over and above coexistence-related welfare losses from reduced trade).

Due to the uncertainty surrounding the average coexistence-related price markup on non-GM food crops, table 10 presents another (sensitivity) simulation which suggests that an average coexistence-related 15 percent price markup on all (organic and conventional) non-GM food crops, which are produced within or exported to EU, would be necessary for coexistence-induced EU welfare losses (-688 mio. US$) to exceed achieved efficiency-induced EU welfare gains (+684 mio. US$).

[Table 11 around here]

Experiment 4 is used to measure potential welfare gains from efficiency improvements associated with increased future adoption of GM food crops in EU (table 11). The analysis is carried out by eliminating EU-specific efficiency gains (productivity improvements and changes in input costs) for GM canola, GM maize, and GM soybean, and the sensitivity analysis indicates that a uniform increase in GM adoption rates for EU-27 leads to an, almost, linear increase in worldwide net welfare benefits. Nonlinearities account for 2-3 percent of the total welfare impact of moving from 25 percent GM adoption rates to the double (50 percent) or triple (75 percent) GM adoption rates. Moreover, net welfare gains, flowing from increased EU adoption of GM food crops, will be appropriated, almost entirely, by EU-27 member countries (98 percent). The main GM food crop producers, including Argentina, Brazil, and US, will incur annual welfare losses < 5 percent of achieved annual welfare gains (due to increased competition in the EU market), while ROW will experience annual welfare gains < 5 percent of achieved annual welfare gains (due to cheaper imports of processed foods).

While potential welfare gains from increased own adoption may be significant for EU, the numbers suggest that achieved trade-related welfare gains, from adoption on the consumption side, are of the same order of magnitude (657 mio. US$). This suggests that EU-27 may not need to adopt biotechnological cropping systems, on the production side, in order to reap (a large part of) the potential welfare gains. Furthermore, the results indicate that increased EU adoption of GM food crops, on the production side, will lead to trade-related welfare losses for the main GM food crop producing countries. Due to widespread public opposition, in EU member states, against biotechnological cropping systems, this suggests that EU-27 and the main GM food crop producing countries may share a common interest in maintaining the current division between (relatively) high EU adoption rates on the consumption side, and a de facto ban of GM food crops on the production side.[9]

In this context, it is interesting to note how the hierarchical institutional set-up governing GM crop regulation in EU distributes de facto decision making power over respectively consumer side and producer side adoption rates. The European Commission (EC) has established a policy framework which distinguishes, strictly, between (1) approval procedures which are supposed to take account of environmental and food safety issues, and (2) coexistence measures which are supposed to deal, more narrowly, with economic spillover effects associated with externalities from GM crop adoption. The EC has de facto decision making power over the approval of GM food crops (based on recommendations by the European Food Safety Authority (EFSA)) due to an institutionalized

[9] Several EU member countries including Austria, Hungary, Luxembourg, Poland, and Slovak Republic have adopted very restrictive regulatory frameworks on coexistence. Combined with small farm sizes and high concentrations of organic farmers, this is likely to work as an effective ban on GM food crops in these member countries. At the same time, other member countries including Czech Republic, Denmark, Germany, Netherland, and Spain have opted for a different regulatory approach based on less restrictive ex ante preventive regulation and innovative ex post liability regulation, which may allow for more widespread GM adoption (Beckman, Soregaroli & Wesseler 2006).

unwritten agreement among EU member states to refrain from creating a qualified majority against the approval of specific GM crops (in order to avoid open conflict with WTO regulation). At the same time, individual member states has de facto decision making power over local GM food crop production since they have been endowed with the power to establish local (excessive) coexistence regulation. Hence, to the extent that EU member states, as a group, prefer to maintain a de facto ban on GM food crop production, this institutional set-up seems to be conducive to the aims of both EU (who would like to avoid the introduction of biotechnological cropping systems) and the main GM food crop producers (who would like to be able to sell their products on the EU market), as long as the EC ensures timely approval of new GM food crops, and as long as national EU policy makers ensures that policy-relevant limitations on GM adoption on the consumption side are minimized.

5. Conclusion

This study has presented a number of general equilibrium simulation experiments, which were designed to measure welfare gains from (1) existing worldwide GM food chain adoption, and (2) potential future increases in GM food chain adoption in EU-27. The evidence suggests that global annual welfare gains, due to efficiency improvements from existing worldwide GM food chain adoption, amounted to 5.8 bio. US$ in 2004. This exceeds existing partial equilibrium welfare estimates of 4.0 bio US$ in 2006 (Brookes & Barfoot 2008), and suggests that (trade-related) general equilibrium effects, associated with existing GM food chain adoption, may be relatively strong. This conclusion is supported by evidence, which suggests that EU member countries has managed to appropriate more than 10 percent of existing worldwide welfare gains (>650 mio. US$ per year) through trade-related spillover effects associated with e.g. imports of GM food crops and GM animal feed. The existence of strong general equilibrium effects underlines the importance of employing a global general equilibrium framework, when evaluating (global and regional) welfare effects of existing and future GM food chain adoption.

Our results also underline the importance of distinguishing between GM adoption rates on the consumption and production side. Hence, our results suggest that the large achieved EU welfare gains have been obtained, mainly, due to adoption on the consumption side (e.g. intermediate consumption of GM animal feed in meat and dairy production), indicating that EU may not need to adopt GM food crops on the production side, in order to reap (a large part of) the potential welfare gains. Furthermore, since our results indicate that the major GM food crop producing countries would experience welfare losses from increased EU adoption on the production side, EU-27 and the main GM food crop producing countries seem to share a common interest in maintaining the current division between (relatively) high EU adoption rates on the consumption side, and a de facto ban of GM food crops on the production side.

The current institutional set-up governing GM crop regulation in EU seems to be well-designed to support the continuation of a (relatively) high EU adoption rate on the consumption side, and a de facto ban of GM food crops on the production side. The European Commission has de facto decision making power over the approval of GM food crops, and, hence, over potential adoption on the consumption side, while individual member states has de facto decision making power over local GM food crop production due to their control over national coexistence regulation. As long as the EC ensures timely approval of new GM food crops, and as long as national EU policy makers ensures that policy-relevant limitations on GM adoption on the consumption side are minimized, this system will be to the mutual benefit of EU member states (to the extent that they, as a group, wants to avoid the introduction of biotechnological cropping systems) and the main GM food crop producing trading partners (who would like to be able to sell their products on the EU market). National limitations on adoption on the consumption side include, in particular, lack of marketing of GM products due to first mover issues among commodity retailers. If national policy makers were to solve this issue, it seems that the interests of EU-27 and the GM food crop producing countries would (to a large extent) align, and, hence, sustain an unholy trade-diverting alliance between these groups of countries.

Finally, our results indicate that welfare losses associated with coexistence-related measures are likely to be relatively small compared to welfare gains from GM-induced efficiency improvements. Based on an average coexistence-related 0.25 percent price markup for non-GM food crops, it was estimated that coexistence-related global welfare losses are negligible, while coexistence-related EU-27 welfare losses are <2 percent of achieved (trade-related) efficiency-induced welfare gains. A sensitivity analysis suggested that an average 15 percent price markup for non-GM food crops would be necessary for coexistence-induced EU welfare losses to exceed achieved (trade-related) efficiency-induced EU welfare gains. Interestingly, our results also suggest that foreign exporters may experience welfare-improvements from (EU-induced) coexistence-related price distortions, to the extent that these regions supply coexistence-related services, themselves.

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Table 1. Regional and sector aggregation of GTAP database

Regional Aggregation	Sector Aggregation
EU-27	non-GM Maize
US	GM Maize
Argentina	Other Cereals
Brazil	non-GM Soybean
Rest of the World	GM Soybean
	non-GM Rapeseed
	GM Rapeseed
	Other Oilseeds
	Other Crops
	Livestock
	Forestry & Fishery
	Meat & Dairy
	non-GM Vegetable Oil
	GM Vegetable Oil
	non-GM Other Food Processing
	GM Other Food Processing
	Chemicals
	Other Industry
	Trade & Transport
-	Other Services

Source: Own calculations based on GTAP Database version 7

Table 2. Assumptions about relative cost shares for GM Maize

	EU-27	US	Argentina	Brazil	ROW
Seeds	+20%	+20%		+5%	+20%
Chemicals	-10%	-10%			
Other Industry Inputs					
Labor					

Table 3. Assumptions about relative cost shares for GM Soybean

	EU-27	US	Argentina	Brazil	ROW
Seeds	+20%	+20%		+5%	+20%
Chemicals	-30%	-30%			
Other Industry Inputs	-15%	-15%	-15%	-15%	-15%
Labor	-10%	-10%	-10%	-10%	-10%

Table 4. Assumptions about relative cost shares for GM Rapeseed

	EU-27	US	Argentina	Brazil	ROW
Seeds	+20%	+20%		+5%	+20%
Chemicals					
Other Industry Inputs					
Labor					

Table 5. Models

Model	Description
Model00	Actual production structure in 2004
Model25	Model0 + uniform 25 percent adoption rate for GM canola, GM maize & GM soybean in EU-27
Model50	Model0 + uniform 50 percent adoption rate for GM canola, GM maize & GM soybean in EU-27
Model75	Model0 + uniform 75 percent adoption rate for GM canola, GM maize & GM soybean in EU-27

Source: Own calculations

Table 6. Experiments

Experiment	Model	Description	Regions
Experiment 1	Model00	Eliminate input cost differences + eliminate uniform 10% productivity gain for GM food crops	All regions
Experiment 2	Model00	Eliminate input cost differences + eliminate uniform 10% productivity gain for GM food crops	EU-27
Experiment 3	Model00	Eliminate average 0.25% coexistence costs on EU imports and domestic production of non-GM food crops	All regions
Experiment 4	Model25, Model50, Model75	Eliminate input cost differences + eliminate uniform 10% productivity gain for GM food crops	EU-27

Source: Own calculations

Table 7. Achieved efficiency gains from worldwide GM food crop adoption in 2004 (mio. US$)

	GM maize	GM canola	GM soybean	Total
EU-27	**85.5**	**6.0**	**591.9**	**683.3**
US	**916.2**	**4.3**	**887.4**	**1808.0**
Argentina	**-4.1**	**-1.9**	**248.7**	**242.7**
Brazil	**-5.8**	**-0.3**	**61.3**	**55.2**
Rest of the World	**837.5**	**41.7**	**2101.1**	**2980.3**
Total	**1829.4**	**49.7**	**3890.4**	**5769.5**

Source: own calculations; Welfare calculations are based on Hicks' equivalent variation measure.

Table 8. Achieved efficiency gains from GM adoption in EU agricultural production in 2004 (mio. US$)

	GM Maize	GM canola	GM soybean	Total
EU-27	**7.2**	**0.0**	**19.2**	**26.4**
US	**-0.4**	**0.0**	**-4.4**	**-4.9**
Argentina	**-1.1**	**0.0**	**-1.9**	**-2.9**
Brazil	**0.0**	**0.0**	**-1.7**	**-1.7**
Rest of the World	**1.4**	**0.0**	**5.3**	**6.6**
Total	**7.1**	**0.0**	**16.4**	**23.5**

Source: own calculations; Welfare calculations are based on Hicks' equivalent variation measure.

Table 9. Achieved efficiency gains in EU from trade spillover effects in 2004 (mio. US$)

	GM Maize	GM Rapeseed	GM Soybean	Total
EU-27	78.2	6.0	572.7	656.9

Source: own calculations; Welfare calculations are based on Hicks' equivalent variation measure.

Table 10. Welfare changes from efficiency gains and coexistence costs in 2004 (mio. US$)

	GM efficiency gains	Non-GM coexistence markup: 0.25%	Non-GM coexistence markup: 15%
EU-27	683.5	-10.2	-687.7
US	1807.4	0.9	62.7
Argentina	242.2	0.4	25.9
Brazil	55.1	7.2	472.1
Rest of the World	2982.7	0.0	2.7
Total	5770.9	-1.7	-124.3

Source: own calculations; Welfare calculations are based on Hicks' equivalent variation measure.

Table 11. Worldwide welfare gains from increased GM food crop adoption in EU-27 by region (mio. US$)

	25 percent GM adoption	50 percent GM adoption	75 percent GM adoption
EU-27	662.8	1336.0	2017.2
US	-13.4	-24.4	-39.0
Argentina	-18.1	-22.0	-29.2
Brazil	-3.5	-10.2	-17.4
Rest of the World	46.7	86.0	132.7
Total	674.6	1365.3	2064.3

Source: own calculations; Welfare calculations are based on Hicks' equivalent variation measure.